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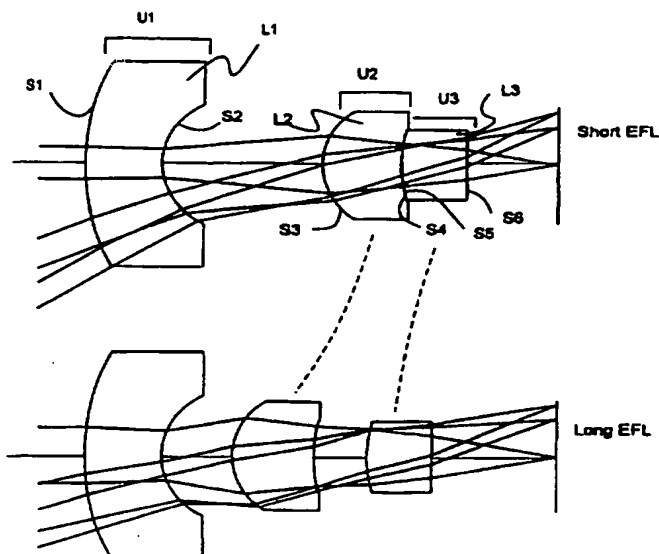
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(54) Title: VARIABLE POWER LENS SYSTEMS FOR PRODUCING SMALL IMAGES



## (57) Abstract

Variable power lens systems for use with electronic imaging systems, e.g., systems employing CCDs, are provided. The systems take advantage of the fact that the images detected by electronic imaging systems are small, e.g., the image diagonal can be 5.5 millimeters or less. The lens systems employ thick lens elements, whose diameters and thicknesses are large relative to the image size, and large air spaces between lens elements. The systems also employ weak lens units. In this way, simplified lens designs having excellent optical properties at less cost are provided. In certain embodiments, the lens systems contain only three lens elements, e.g., a negative first lens element (L1), a positive second lens element (L2) for zooming, and a positive third lens element (L3), with the first (L1) and/or the third lens element (L3) serving as a compensator.

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5      VARIABLE POWER LENS SYSTEMS FOR PRODUCING SMALL IMAGESFIELD OF THE INVENTION

10      This invention relates to variable power lens systems, particularly zoom lens systems, for use in producing small images. In certain embodiments of the invention, the small images produced by the lens system are detected by an electronic imaging system, e.g., a system employing a charged coupled device (CCD) or similar light sensitive electronic component. Such systems are well known in the art and descriptions thereof can be found in various references, including Rose et al., "Physical Limits to the Performance of Imaging Systems," Physics Today, September 1989, pages 24-32 and the references cited therein; and Séquin et al., "Charge Transfer Devices," Advances in Electronics and Electron Physics, suppl. 8, L. Marton editor, Academic Press, New York, 1975, the relevant portions of all of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

25      Electronic imaging systems have the advantage of being able to work with images of small size. For example, CCDs having a diagonal of approximately 4 mm (known as 1/4 inch CCDs) are widely available. CCDs having diagonals of 5.5 mm (1/3 inch CCDs) are also widely used. Within this small size, a typical CCD will have over 200,000 pixels, thus giving the device a resolution on the order of 70 cycles per millimeter at the surface of the CCD.

35      In the past, fixed focal length lens systems have been used with CCDs. For many applications, such systems are inadequate because a fixed focal length system cannot simultaneously provide a large angle of view and

sufficient resolution to allow detailed examination of specific parts of the field of view. Although electronic zooming can be performed, i.e., zooming wherein a portion of the field is selected and electronically magnified to fill the entire viewing screen, such zooming does not increase the resolution of the original image captured by the CCD. Alternatively, the resolution of the original image can be improved by increasing the number of CCD pixels, but this approach significantly adds to the cost of the device and diffraction effects limit the extent to which pixel size can be reduced.

There thus exists a need for variable power lens systems for use with electronic imaging systems. As known in the art, variable power lens systems can have a discrete number of focal lengths at which the image is in focus at a fixed location, e.g., a dual power system, or can have a focal length which can vary continuously while producing a focused image at a fixed location, e.g., a zoom lens system. Alternatively, the image location need not be kept fixed, in which case, either the detecting device, e.g., the CCD, or the lens system can be moved as the focal length of the lens system is varied either discretely or continuously. The present invention provides variable power lens systems for use with any of these configurations.

A variety of zoom lens systems are known in the art. Examples include Tsuchida et al., U.S. Patent No. 4,810,071, Mihara et al., U.S. Patent No. 4,906,079, Hata, U.S. Patent No. 5,009,491, and Ozawa, U.S. Patent No. 5,054,897. Lens systems of these types have been developed in accordance with the following principles of conventional lens design practice:

(1) The manufacturing cost of a lens element is primarily determined by the volume of the element and its surface area. For this reason, for most commercial applications, lens designers try to minimize lens element diameters and thicknesses relative to the image size.

(2) In zoom lens design, one or both of the pupils typically moves during zooming. This means that lens diameters must be increased to transmit the entire imaging bundle throughout the zooming range. To minimize this increase in lens diameters (see principle (1) above), lens designers typically use lens elements of relatively large powers. This, in turn, results in increased aberration contributions because of the large powers, and necessitates the inclusion of more lens elements for aberration correction. Conventional wisdom, however, has been to opt for more lens elements, as opposed to larger elements.

Ohno, U.S. Patent No. 5,357,374, discloses a zoom lens system for use in a photographic camera that employs three lens elements in a negative-positive-negative or a negative-positive-positive arrangement. The Ohno lens system employs strong, thin lens elements which introduce substantial aberrations into the system such that the smallest f-number reported for any of Ohno's examples is 7.6. The Ohno system is limited to such relatively small apertures since the aberrations of the system would become excessive if the aperture were increased. In contrast, the lens systems of the present invention achieve large apertures through the use of weak, thick lens elements.

#### SUMMARY OF THE INVENTION

In accordance with the present invention, it has been found that the conventional approaches discussed above lead to overly expensive and complicated designs when applied to the problem of providing a large aperture, variable power lens system which produces a small image suitable for detection by an electronic imaging system. Specifically, in accordance with the invention, it has been found that by increasing the thicknesses of lens elements relative to the image size, as well as by increasing air spaces between lens elements, simplified lens designs having excellent

optical properties at less cost can be provided. In particular, in certain embodiments, lens units containing only one lens element can be used with the system still having excellent overall aberration correction.

5           This effect occurs because although manufacturing costs are reduced as the volume of a lens element goes down, a point is reached where this cost reduction levels off. This point of diminishing cost reduction generally corresponds to lens elements whose diameters are less  
10           than about 10 millimeters. As such, these diameters are large relative to the size of the images which are detected by electronic imaging systems, even though from a cost point of view the lens elements are small.

          Accordingly, thick lens elements whose diameters and  
15           thicknesses are large relative to the image size, but whose absolute size is small, are used in the practice of the present invention. Such thick lens elements allow for the use of lens surfaces having reduced power. This, in turn, reduces the aberrations produced by the  
20           surfaces. In addition, because the lens elements have an overall small absolute size, they can be economically molded in either glass or plastic. Such molding, in turn, permits the use of aspherical surfaces, which can be configured to further reduce the aberrations of the  
25           system.

          The variable power lens systems of the invention include three lens units. The first and second lens units from the object end of the system have a negative and a positive power, respectively. The third lens unit  
30           generally has a positive power, but may be negative in some cases. Each of the three lens units includes one or more lens elements.

          The first and second units have powers whose magnitudes are small relative to the overall strongest  
35           power of the system. In particular, the absolute values of the focal lengths of at least one and preferably both of the first and second units of the lens system is

greater than about 1.3 times  $f_{\min}$ , where  $f_{\min}$  is the focal length of the system at its shortest focal length position, i.e., its widest field of view. Similarly, the third lens unit is generally also weak, i.e., its focal length is generally greater than about 1.3 times  $f_{\min}$ .

In addition to having weak lens units, the lens systems of the invention also have thick lens elements. In particular, the lens systems include at least one lens element whose thickness is greater than about 0.5 times  $f_{\min}$ , and preferably include at least two such lens elements and in some cases at least three such elements. In some embodiments, one of the thick lens elements may be part of a color correcting doublet (see Example 7).

In certain embodiments of the invention, the first lens unit and/or the second lens unit includes a surface which has a relatively strong power in comparison to the overall power of the unit in which it is contained. These strong surfaces serve to provide aberration correction for the lens system.

In other embodiments, the third lens unit has a positive power and includes a surface at its image side that is concave to the image. This surface also provides aberration correction for the lens system.

As illustrated by the examples presented below, the invention can provide variable power lens systems and, in particular, zoom lens systems having a limited number of lens elements, each of low power relative to the overall power of the system, e.g., in some cases, only three lens elements of relatively low power, rather than many lens elements at least some of which are very strong, as in the prior art. Such lens systems provide a cost effective way to produce small images of varying magnification for detection by an electronic imaging system.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1 through 9 are schematic side views of lens systems constructed in accordance with the invention. The upper portion of each of these figures shows the lens

system in its short effective focal length (EFL) configuration, while the lower portion shows it in its long EFL configuration.

5        These drawings, which are incorporated in and constitute part of the specification, illustrate the preferred embodiments of the invention, and together with the description, serve to explain the principles of the invention. It is to be understood, of course, that both the drawings and the description are explanatory only and  
10        are not restrictive of the invention.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

As discussed above, the present invention relates to variable focal length lens systems employing weak lens units and lens elements of substantial thickness. By  
15        utilizing weak units, thick elements, and aspheric surfaces, the invention can achieve large apertures of  $f/2.0$  or less and a wide total field of view of 70 degrees or more.

Also, a wide range of zoom ratios can be achieved.  
20        In particular, in the simplest case, a 2:1 zoom ratio can be achieved using just three single lens elements, i.e., a negative first lens element, a positive second lens element that moves to effect a change of internal magnification during zooming, and a positive third lens  
25        element, where either or both of the first and third lens elements moves to provide compensation when zooming.

If the focal length is increased, either by increasing the zoom ratio or by changing the zooming region to longer focal lengths, then correction of  
30        residual chromatic aberrations may be necessary. This can be achieved by compounding only the third lens unit. (As used herein and in the claims, a compounded component, e.g., a doublet, is not a "single lens element.")

35        As an alternative, the third lens unit can include a diffractive surface to correct the chromatic aberration, e.g., the third lens unit can be composed of

an element that is fabricated as a refractive-diffractive hybrid element. The fabrication of such elements is well known in the art. See, for example, C. Londoño, "Design and Fabrication of Surface Relief Diffractive Optical Elements, or Kinoforms, with Examples for Optical Athermalization," Ph.D. diss., Tufts University, 1992, and the references cited therein, the relevant portions of all of which are incorporated herein by reference. Diffractive surfaces have the problem of diffraction efficiency, i.e., all orders do not come to a perfect focus. This effect is often seen as "glare". For an electronic imaging system application, the diffraction efficiency problem can be addressed by digital processing of the electronic image.

If desired, chromatic aberration can be corrected in the first and/or the second lens units, either alone or in combination with correction in the third lens unit, although correction in just the third lens unit is most preferred.

For monochromatic CCDs, it is generally not important that the exit pupil of the lens system is telecentric. In this case, the preferred location of the aperture stop is after the second unit. When a telecentric or near telecentric exit pupil is required, e.g., for color CCDs, the aperture stop can be moved to a position before or within the second unit.

If only a change of focal length (field of view) between two extremes is required, the first and third units can be fixed and a positive second unit can be moved to change focal length without requiring refocusing for the two extremes.

To increase the zoom range, a fixed positive lens unit (U4) can be placed before the negative first lens unit. In this design, the negative first lens unit becomes the focal length variator for zooming and the positive second lens unit becomes the compensator. As

illustrated in Example 6, the second and third lens units can be moved together for compensating, if desired.

Because the lens units making up the lens systems of the invention have small mass, they can be easily moved using low powered devices, such as, small motors, electromagnetics, and the like. Accordingly, the lens systems can be mounted directly on a circuit board which carries a CCD or similar device.

#### EXAMPLES

Without intending to limit it in any manner, the present invention is illustrated by the examples of Figures 1-9 and the corresponding prescriptions of Tables 1-9. Lens units, lens elements, and lens surfaces are identified by "U", "L", and "S" numbers, respectively, in the figures.

As is conventional, the figures are drawn with the long conjugate on the left and the short conjugate on the right. Accordingly, in the typical application of the invention, the object to be viewed will be on the left and an electronic imaging system, e.g., a system employing a CCD, will be on the right.

The glasses and plastics referred to in Tables 1-9 are set forth in Table 10, where the glass names are the SCHOTT and HOYA designations. Equivalent materials made by other manufacturers can be used in the practice of the invention.

The aspheric coefficients set forth in the tables are for use in the following equation:

$$z = \frac{cy^2}{1 + [1 - (1 + k)c^2y^2]^{1/2}} + ADy^4 + AEy^6 + AFy^8 + AGy^{10} + AHy^{12} + AIy^{14}$$

where z is the surface sag at a distance y from the optical axis of the system, c is the curvature of the lens at the optical axis, and k is a conic constant, which is zero except where indicated.

The abbreviations used in the tables are as follows:  
SN - surface number; CLR. AP. - clear aperture; FIELD --  
half field of view; EFL - effective focal length; FVD -  
front vertex distance;  $f/$  - f-number; BFL - back focal  
length; ENP - entrance pupil; EXP - exit pupil, and BRL -  
barrel length. The designations "a" and "ac" associated  
with various surfaces represent "aspheric" and "aspheric  
with a conic constant", respectively. The asterisks used  
in Tables 4 and 5 represent a diffractive surface. All  
dimensions given in the tables are in millimeters.

#### Example 1

This example shows a three element zoom lens system  
having a negative first lens unit, a positive second lens  
unit, and a positive third lens unit. The first lens unit  
is fixed during zooming, the second lens unit provides  
the change in magnification of the system, and the third  
lens unit is the compensator. This system provides a 1.7  
zoom ratio from 3.8 mm to 6.5 mm.

#### Example 2

This example shows another three element zoom lens  
system having a negative first lens unit which remains  
fixed during zooming, a positive second lens unit which  
moves to change the system's focal length, and a positive  
third lens unit which serves as the compensator. This  
system has a 2.0 zoom ratio and a maximum field of view  
of 72° at an aperture of  $f/1.7$ . The lens system of this  
example has a larger field of view, i.e., a shorter focal  
length, than that of Example 1 and uses the thickness of  
the front lens element to provide a higher level of field  
curvature correction than in Example 1.

#### Example 3

This example illustrates the use of a color  
correcting doublet in the third lens unit. As in  
Examples 1 and 2, the first lens unit is negative and  
remains fixed during zooming, the second lens unit is  
positive and moves to change the system's focal length,

and the third lens unit is positive and serves as the compensator. The zoom ratio for this system is 1.84.

#### Examples 4 and 5

5 These examples illustrate the use of a diffractive surface (S6/S7) in the third lens unit to provide for color correction. The asterisks in the tables for these examples represent the index of refraction and the Abbe numbers used in the Sweatt model for a diffractive surface, e.g., a  $N_e$  value of 9999 and a  $V_e$  value of -3.4.

10 See W.C. Sweatt, "Mathematical Equivalence between a Holographic Optical Element and an Ultra High Index Lens," Journal of the Optical Society of America, 69:486-487, 1979. In each of these examples, the first lens unit is negative and fixed, the second lens unit is

15 positive and moves for zooming, and the third lens unit is positive and serves as the compensator.

#### Example 6

This example illustrates the use of a positive lens unit (U4) on the object side of the first lens unit (U1).

20 This positive lens unit serves to increase the zooming range of the system, in this case, to 2.25. The system of this example moves the first lens unit for zooming and the second and third lens units for compensating. The third lens unit includes a color correcting doublet.

#### Example 7

25 This example illustrates a system having a distant exit pupil. The first lens unit is negative and fixed during zooming. The second lens unit is positive and moves between the first and third lens units to provide

30 dual power without a change in focus position. The third lens unit is a positive doublet which provides color correction. The aperture stop for this system is within the second lens unit and moves with that unit. For certain applications, e.g., the viewing of documents, the

35 system can be focused at different object distances for its different focal lengths for a constant image distance, e.g., the system can be focused at infinity for

its short focal length position and can be focused at a closer distance, e.g., 25-50 centimeters, for its long focal length position.

#### Example 8

5           This example is similar to the lens system of Example 2 wherein the third unit has been compounded for color correction. Surfaces S6 and S7 are each approximately paraboloidal so as to provide large surface powers for effective color correction.

#### Example 9

10           This example is also similar to the lens system of Example 2. In this case, the third unit is composed of two identical lens elements which allows for enhanced aberration correction without a substantial increase in the overall cost of the system.

15           Of the foregoing examples, Examples 1-6 are zoom systems, while Examples 7-9 are dual power systems. In particular, Examples 7-9 are designed to produce a 2:1 change in magnification between their long and short focal length positions.

20           In the case of dual power systems, it should be noted that the same optical elements can be used to produce a magnification range other than 2:1 by simply changing the limits of motion of the second lens unit and the spacing between the lens system and the image plane. This can be done through the use of a lens barrel that includes changeable stops for the second lens unit and a mounting system for the lens barrel which allows for changes in the spacing between the barrel and the image plane. Alternatively, the same lens elements can be used with different lens barrels having different stops and/or with different lens barrel mounts which provide different spacings between the lens system and the image plane.

25           Tables 11-14 summarize various properties of the lens systems of Figures 1-9. In particular, Table 11 sets forth the powers of the first, second, and third units ( $\Phi_{U1}$ ,  $\Phi_{U2}$ ,  $\Phi_{U3}$ ), and the powers of the strongest

5       concave-to-the-image surface of the first and second  
units ( $\Phi_{U1S}$ ,  $\Phi_{U2S}$ ). Note that the second unit of the lens  
system of Example 7 does not include a surface that is  
concave to the image. As shown by this table, all of the  
10       lens systems of the invention include at least one  
concave-to-the-image surface which is strong relative to  
the power of the unit, i.e.,  $\Phi_{U1S}/\Phi_{U1} > 1.0$  or  $\Phi_{U2S}/\Phi_{U2} >$   
1.0, and many of the systems have such a surface in both  
the first and second units, i.e.,  $\Phi_{U1S}/\Phi_{U1} > 1.0$  and  
15        $\Phi_{U2S}/\Phi_{U2} > 1.0$ .

Table 12 sets forth the operating magnification of  
each of the units at its short focal length position ( $M_w$ )  
and its long focal length position ( $M_t$ ). In Examples 1-5  
and 7-9, the first unit is at the object end of the lens  
15       system and thus its operating magnification is always  
zero. Accordingly, Table 12 does not contain entries for  
the first unit for these examples.

As is well known, the focal length of an optical  
system can be expressed as the product of the focal  
20       length of the system's unit closest to the object and the  
product of the operating magnifications of the following  
units. Accordingly, for a variable focal length system,  
the unit which contributes most to the change in focal  
length of the system between its maximum and minimum  
25       focal lengths can be determined by forming the ratio of  
the operating magnifications of the units of the system  
at the maximum and minimum focal lengths of the system,  
i.e.,  $M_t/M_w$ . This ratio is set forth in Table 12 and  
shows that for the lens systems of the invention, it is  
30       the second unit which provides the majority of the change  
in focal length of the system between its maximum and  
minimum effective focal lengths.

Table 13 sets forth the focal lengths of the first,  
second, and third units ( $f_1$ ,  $f_2$ ,  $f_3$ ) and compares those  
35       focal lengths to the minimum focal length of the system  
( $f_{min}$ ). As can be seen in this table, for all of the  
examples, the first and second lens units are relatively

weak in that their focal lengths are greater than 1.3 times the minimum focal length of the system. Similarly, the  $f_3/f_{\min}$  ratio is greater than 1.3 for all of the examples.

5           Table 14 sets forth the ratios of the thicknesses ( $T_1$ ,  $T_2$ ,  $T_3$ ,  $T_4$ , and  $T_5$ ) of the various lens elements of Examples 1-9 to  $f_{\min}$ . As shown in this table, all of the examples have at least one lens element for which the ratio is greater than 0.5, two of the examples (Examples  
10       3 and 9) have two lens elements of this type, five of the examples (Examples 1, 2, 4, 6, and 8) have three such lens elements, and one example (Example 7) has four such elements. The use of thick lens elements in the lens systems of the invention is thus evident from Table 14.

15           Although specific embodiments of the invention have been described and illustrated, it is to be understood that a variety of modifications which do not depart from the scope and spirit of the invention will be evident to persons of ordinary skill in the art from the foregoing  
20       disclosure. The following claims are intended to cover the specific embodiments set forth herein as well as such modifications, variations, and equivalents.

TABLE 1

SN.	RADIUS	THICKNESS	GLASS	CLR. AP.
1 a	10.6068	2.94249	SK5	8.78
2	2.8047	space 1		4.81
3	2.7212	3.09514	FK5	4.24
4 ac	9.2271	space 2		2.88
5 a	4.8690	2.53252	SK5	2.34
6	127.0755			2.69

## CONICS SURF. CONST. - k

4 -1.0000E+00

## ZOOM THICKNESSES

EFL space 1 space 2

3.8 6.123 0.000

4.9 4.484 1.200

6.5 2.736 2.026

## EVEN POLYNOMIAL ASPHERES

SN	AD	AE	AF	AG	AH	AI
1	1.5125E-04	6.0814E-06	1.3343E-07	-1.1696E-10	-1.8823E-11	0.0000E+00
4	9.1628E-03	1.4307E-03	3.3105E-04	1.5987E-04	2.5426E-06	7.5636E-06
5	-6.5629E-03	2.1341E-03	8.2481E-04	-3.0731E-04	-2.7285E-04	6.4932E-05

## SYSTEM FIRST ORDER PROPERTIES, POS 1

FIELD: 32.0° f/ 2.80

STOP: 0.00 after surface 4. DIA: 1.8567

EFL: 3.80557 FVD: 18.2149 ENP: 6.94365

BFL: 3.52208 BRL: 14.6929 EXP: -1.57966

## SYSTEM FIRST ORDER PROPERTIES, POS 2

FIELD: 23.0° f/ 2.80

STOP: 1.20 after surface 4. DIA: 1.9723

EFL: 4.89295 FVD: 18.1558 ENP: 7.42769

BFL: 3.90117 BRL: 14.2547 EXP: -1.57966

## SYSTEM FIRST ORDER PROPERTIES, POS 3

FIELD: 19.0° f/ 2.80

STOP: 2.03 after surface 4. DIA: 2.3075

EFL: 6.49324 FVD: 18.1529 ENP: 7.93326

BFL: 4.82045 BRL: 13.3325 EXP: -1.57966

TABLE 2

SN.	RADIUS	THICKNESS	GLASS	CLR. AP.
1 a	13.3243	4.38830	ACRYLIC	11.74
2 a	2.5110	Space 1		4.83
3 a	5.3905	4.12155	FC5	3.74
4	-3.9133	Space 2		2.62
5 a	3.0405	3.81871	FC5	3.33
6 a	3.4578			3.89

## ZOOM THICKNESS

EFL	Space 1	Space 2
2.75	4.398	0.468
4.0	2.249	2.797
5.5	0.644	3.998

## EVEN POLYNOMIAL ASPHERES

SN	AD	AE	AF	AG	AH	AI
1	1.4639E-03	2.6163E-05	-4.8682E-07	-5.8626E-09	7.8908E-11	8.5932E-14
2	8.5350E-03	1.5387E-03	9.7529E-05	-8.0871E-06	-1.8211E-06	7.8755E-07
3	1.9156E-03	-1.1891E-03	-8.9141E-04	5.0152E-04	-1.1451E-04	9.0080E-06
5	-5.6232E-03	-2.0760E-03	2.4941E-04	9.7952E-05	5.5174E-06	-7.5037E-06
6	-6.2186E-02	2.4896E-04	6.7076E-03	-5.2346E-04	-4.7997E-04	7.1999E-05

## SYSTEM FIRST ORDER PROPERTIES, POS 1

FIELD: 36.0° f/ 1.70  
 STOP: 0.00 after surface 4. DIA: 2.5333  
 EFL: 2.75018 FVD: 20.0004 ENP: 9.81765  
 BFL: 0.805822 BRL: 19.1946 EXP: -2.14066

## SYSTEM FIRST ORDER PROPERTIES, POS 2

FIELD: 26.5° f/ 2.10  
 STOP: 0.00 after surface 4. DIA: 2.5447  
 EFL: 4.00022 FVD: 20.0005 ENP: 9.19297  
 BFL: 0.625972 BRL: 19.3746 EXP: -3.67391

## SYSTEM FIRST ORDER PROPERTIES, POS 3

FIELD: 18.0° f/ 2.50  
 STOP: 0.00 after surface 4. DIA: 2.5489  
 EFL: 5.49945 FVD: 20.0002 ENP: 8.56414  
 BFL: 1.02967 BRL: 18.9706 EXP: -4.67093

TABLE 3

SN.	RADIUS	THICKNESS	GLASS	CLR. AP.
1 a	16.9962	2.50844	SK5	9.06
2	3.1866	space 1		5.30
3	2.8898	3.21633	FK5	4.54
4 ac	7.1808	space 2		3.19
5 a	3.2207	1.14834	SK5	2.97
6	-3.7108	1.44272	STYRENE	2.94
7 a	6.5050			2.80

CONICS SURF. CONST. - k

4 -1.0000E+00

## ZOOM THICKNESSES

EFL	space 1	space 2
3.8	6.595	0.000
4.9	4.885	1.093
6.5	3.163	1.690
7.0	2.763	1.630

## EVEN POLYNOMIAL ASPHERES

SN	AD	AE	AF	AG	AH	AI
1	7.7828E-05	1.1677E-05	-8.8761E-08	-1.3523E-08	4.3159E-10	0.0000E+00
4	1.0506E-02	-8.6755E-04	1.3016E-03	3.3806E-04	-3.8492E-04	9.8656E-05
5	3.1087E-04	-3.4019E-04	5.3088E-04	2.4463E-05	-1.3487E-04	3.6458E-05
7	1.0152E-02	4.4352E-04	3.2070E-04	1.6785E-04	2.4794E-05	-1.1762E-05

## SYSTEM FIRST ORDER PROPERTIES, POS 1

FIELD: 36.0° f/ 2.60

STOP: 0.00 after surface 5. DIA: 2.2449

EFL: 3.80511 FVD: 18.3342 ENP: 6.16736

BFL: 3.42291 BRL: 14.9113 EXP: -1.41523

## SYSTEM FIRST ORDER PROPERTIES, POS 2

FIELD: 27.0° f/ 2.80

STOP: 0.00 after surface 5. DIA: 2.3083

EFL: 4.89981 FVD: 18.2984 ENP: 6.45515

BFL: 4.00483 BRL: 14.2935 EXP: -1.41523

## SYSTEM FIRST ORDER PROPERTIES, POS 3

FIELD: 23.0° f/ 2.80

STOP: 0.00 after surface 5. DIA: 2.8031

EFL: 6.50269 FVD: 18.2978 ENP: 6.61304

BFL: 5.12847 BRL: 13.1693 EXP: -1.41523

TABLE 3 (continued)

## SYSTEM FIRST ORDER PROPERTIES, POS 4

FIELD: 19.0° f/ 2.80

STOP: 0.00 after surface 5. DIA: 2.9893

EFL: 6.99986 FVD: 18.2987 ENP: 6.51301

BFL: 5.58981 BRL: 12.7089 EXP: -1.41523

TABLE 4

SN.	RADIUS	THICKNESS	GLASS	CLR. AP.
1 a	10.6067	2.94248	SK5	8.78
2	2.8047	space 1		4.81
3	2.7400	3.09513	FCD1	4.28
4 ac	8.6000	space 2		2.86
5 a	5.2500	2.53200	SK5	2.34
6	diffractive	0.00100	*****	2.72
7	surface			2.72

CONICS SURF. CONST. - k

4 -1.0000E+00

## ZOOM THICKNESSES

EFL	space 1	space 2
3.8	6.123	0.000
4.9	4.485	1.222
6.5	2.736	1.988

## EVEN POLYNOMIAL ASPHERES

SN	AD	AE	AF	AG	AH	AI
1	1.5125E-04	6.0816E-06	1.3344E-07	-1.1696E-10	-1.8824E-11	0.0000E+00
4	9.1629E-03	1.4308E-03	3.3106E-04	1.5987E-04	2.5427E-06	7.5641E-06
5	-6.5630E-03	2.1341E-03	8.2484E-04	-3.0732E-04	-2.7287E-04	6.4936E-05

## SYSTEM FIRST ORDER PROPERTIES, POS 1

FIELD: 32.0° f/ 2.80

STOP: 0.00 after surface 4. DIA: 1.8602

EFL: 3.82615 FVD: 18.3068 ENP: 6.94170

BFL: 3.61318 BRL: 14.6936 EXP: -1.61675

## SYSTEM FIRST ORDER PROPERTIES, POS 2

FIELD: 23.0° f/ 2.80

STOP: 1.22 after surface 4. DIA: 1.9765

EFL: 4.91587 FVD: 18.2807 ENP: 7.44774

BFL: 4.00305 BRL: 14.2776 EXP: -1.61675

## SYSTEM FIRST ORDER PROPERTIES, POS 3

FIELD: 19.0° f/ 2.80

STOP: 1.99 after surface 4. DIA: 2.3125

EFL: 6.48543 FVD: 18.2817 ENP: 7.89910

BFL: 4.98707 BRL: 13.2946 EXP: -1.61675

TABLE 5

SN.	RADIUS	THICKNESS	GLASS	CLR. AP.
1 a	11.3121	0.92031	SK5	6.64
2 a	2.5168	space 1		4.57
3	2.5779	2.73342	FK5	3.10
4 ac	9.3302	space 2		2.46
5 a	6.0273	1.00000	SK5	2.68
6	diffractive	0.02057	*****	2.71
7	surface			2.71

## CONICS SURF. CONST. - k

4 -1.0000E+00

## ZOOM THICKNESSES

EFL	space 1	space 2
2.8	7.504	0.063
3.5	5.926	1.390
4.7	4.170	2.291

## EVEN POLYNOMIAL ASPHERES

SN	AD	AE	AF	AG	AH	AI
1	1.6978E-03	2.8210E-04	-3.7877E-05	1.2685E-07	1.1266E-07	-2.2722E-09
2	7.7378E-04	-3.8418E-04	5.0744E-04	-1.2590E-04	4.5972E-06	6.1899E-08
4	1.3014E-02	2.1291E-02	-6.3545E-02	8.1041E-02	-4.4352E-02	8.8687E-03
5	-1.9676E-03	-5.8404E-03	1.0048E-02	-8.2147E-03	3.3279E-03	-5.2434E-04

## SYSTEM FIRST ORDER PROPERTIES, POS 1

FIELD: 36.0° f/ 2.60  
 STOP: 0.00 after surface 4. DIA: 1.9529  
 EFL: 2.76018 FVD: 16.5538 ENP: 4.42462  
 BFL: 4.31250 BRL: 12.2413 EXP: -.699053

## SYSTEM FIRST ORDER PROPERTIES, POS 2

FIELD: 27.0° f/ 2.80  
 STOP: 0.00 after surface 4. DIA: 2.1003  
 EFL: 3.54444 FVD: 16.5542 ENP: 4.19785  
 BFL: 4.56401 BRL: 11.9902 EXP: -2.31176

## SYSTEM FIRST ORDER PROPERTIES, POS 3

FIELD: 23.0° f/ 2.80  
 STOP: 0.00 after surface 4. DIA: 2.4543  
 EFL: 4.70592 FVD: 16.5547 ENP: 3.87829  
 BFL: 5.41942 BRL: 11.1353 EXP: -3.77642

TABLE 6

SN.	RADIUS	THICKNESS	GLASS	CLR. AP.
1	12.7245	3.00000	ACRYLIC	11.10
2 a	404.1860	space 1		9.19
3 a	-45.1943	2.57119	SK5	9.00
4	3.5966	space 2		5.35
5	3.1880	3.27368	FK5	3.80
6 ac	6.8115	space 3		2.90
7 a	3.4793	1.14834	SK5	3.06
8	-4.0125	1.52903	STYRENE	3.03
9 a	10.9772			2.93

CONICS SURF. CONST. - k

6 -1.0000E+00

## ZOOM THICKNESSES

EFL	space 1	space 2	space 3
4.0	0.274	7.981	0.038
5.5	1.305	5.580	0.759
8.0	2.386	3.179	0.896
9.0	3.297	2.727	0.104

## EVEN POLYNOMIAL ASPHERES

SN	AD	AE	AF	AG	AH	AI
2	6.1059E-05	2.9993E-06	-1.6302E-08	-1.0399E-09	-1.7818E-11	4.5793E-13
3	2.4601E-04	9.2334E-06	-8.4630E-08	-1.2976E-08	-2.9683E-10	2.3802E-11
6	8.3243E-03	-2.0301E-03	1.1581E-03	3.7123E-04	-3.7592E-04	8.1376E-05
7	5.0383E-04	1.3227E-04	-2.5209E-05	-1.8024E-05	2.1934E-06	5.0602E-06
9	7.7885E-03	4.4442E-04	1.1285E-04	2.6862E-05	-3.7025E-06	-1.7560E-06

## SYSTEM FIRST ORDER PROPERTIES, POS 1

FIELD: 29.0° f/ 2.60

STOP: 0.00 after surface 6. DIA: 2.2609

EFL: 3.99978 FVD: 23.5006 ENP: 10.4532

BFL: 3.68488 BRL: 19.8157 EXP: -1.57165

## SYSTEM FIRST ORDER PROPERTIES, POS 2

FIELD: 23.0° f/ 2.80

STOP: 0.00 after surface 6. DIA: 2.3814

EFL: 5.50059 FVD: 23.4999 ENP: 11.9398

BFL: 4.33332 BRL: 19.1666 EXP: -2.23994

TABLE 6 (continued)

## SYSTEM FIRST ORDER PROPERTIES, POS 3

FIELD: 15.0° f/ 2.80

STOP: 0.00 after surface 6. DIA: 2.7787

EFL: 8.00048 FVD: 23.5004 ENP: 13.3951

BFL: 5.51748 BRL: 17.9829 EXP: -2.38151

## SYSTEM FIRST ORDER PROPERTIES, POS 4

FIELD: 13.0° f/ 2.80

STOP: 0.00 after surface 6. DIA: 2.8669

EFL: 9.00135 FVD: 23.4998 ENP: 15.3327

BFL: 5.84972 BRL: 17.6500 EXP: -1.62798

TABLE 7

SN.	RADIUS	THICKNESS	GLASS	CLR. AP.
1 a	6.2798	3.81301	ACRYLIC	10.53
2 a	2.3184	Space 1		4.62
3 a	-8.6346	2.28707	FK5	2.70
4 a	-2.5287	Space 2		3.04
5 a	4.4628	1.42354	SF2	4.68
6	2.3232	3.76900	FK5	4.18
7 a	-2.4592			4.46

## EVEN POLYNOMIAL ASPHERES

SN	AD	AE	AF	AG	AH	AI
1	-1.2527E-03	-7.9555E-07	1.4713E-06	5.5037E-08	1.5157E-09	-9.3093E-12
2	-1.2812E-02	-8.1660E-05	-2.8414E-04	-1.1018E-05	1.6584E-05	6.2920E-06
3	-6.9214E-03	-1.1828E-02	-2.6848E-03	1.3200E-03	8.4427E-04	-2.8703E-04
4	5.8279E-03	-5.1619E-03	-5.5055E-04	7.3209E-04	2.3819E-04	-1.1639E-04
5	-2.1316E-03	6.1825E-04	9.9131E-07	-4.8820E-06	-1.5303E-06	2.2678E-07
7	2.9516E-02	-1.6791E-03	-1.9826E-04	3.9826E-05	2.0340E-05	-2.2356E-06

## ZOOM THICKNESSES

EFL	Space 1	Space 2
2.75	5.053	0.323
5.50	0.450	4.926

## SYSTEM FIRST ORDER PROPERTIES, POS 1

FIELD: 38.0° f/ 1.70  
 STOP: 1.14 after surface 3. DIA: 2.3232  
 EFL: 2.75008 FVD: 18.0732 ENP: 8.64115  
 BFL: 1.40448 BRL: 16.6687 EXP: -47.9927

## SYSTEM FIRST ORDER PROPERTIES, POS 2

FIELD: 18.0° f/ 2.50  
 STOP: 1.14 after surface 3. DIA: 2.1085  
 EFL: 5.50013 FVD: 18.0731 ENP: 4.82781  
 BFL: 1.40448 BRL: 16.6686 EXP: 8.17937

TABLE 8

SN.	RADIUS	THICKNESS	GLASS	CLR. AP.
1	8.4213	4.14796	POLYCARB	12.31
2 ac	2.5363	Space 1		5.89
3 a	6.4257	5.50000	ACRYLIC	4.76
4	-5.3740	Space 2		5.03
5 a	4.9351	2.62000	ACRYLIC	4.59
6 ac	-2.6931	0.02000		4.61
7 ac	-2.4850	1.45000	POLYCARB	4.55
8 a	14.9612			4.52

## CONICS SURF. CONST. - k

2	-1.0000E+00
6	-1.0000E+00
7	-1.0000E+00

## EVEN POLYNOMIAL ASPHERES

SN.	AD	AE	AF	AG	AH	AI
2	4.7387E-03	2.0774E-04	4.0578E-05	-1.7764E-06	-2.9975E-07	6.5544E-08
3	-4.9014E-04	-7.3601E-05	-1.6738E-07	-9.2270E-07	-1.8249E-07	6.9122E-08
5	-1.6121E-03	8.8969E-05	-4.9125E-05	-5.4489E-06	1.2664E-07	-2.1226E-08
6	-1.7529E-03	4.6796E-05	3.3765E-05	4.3332E-06	7.0086E-08	2.8772E-08
7	1.7980E-03	2.3259E-04	1.4868E-05	1.5478E-06	6.0858E-07	5.8231E-08
8	4.7626E-03	-2.8658E-04	2.9452E-05	1.0259E-05	-7.7642E-08	-3.8091E-07

## ZOOM THICKNESS

EFL	Space 1	Space 2
4.0	7.844	0.384
8.0	2.847	5.380

## SYSTEM FIRST ORDER PROPERTIES, POS 1

FIELD: 34.5° f/ 1.80  
 STOP: 3.63 after surface 3. DIA: 4.0816  
 EFL: 3.99991 FVD: 25.0803 ENP: 9.45134  
 BFL: 3.11468 BRL: 21.9656 EXP: -3.57716

## SYSTEM FIRST ORDER PROPERTIES, POS 2

FIELD: 18.9° f/ 2.30  
 STOP: 3.63 after surface 3. DIA: 4.6708  
 EFL: 7.99984 FVD: 25.0803 ENP: 7.89693  
 BFL: 3.11493 BRL: 21.9654 EXP: -7.75983

TABLE 9

SN.	RADIUS	THICKNESS	GLASS	CLR. AP.
1 a	15.7205	7.27585	STYRENE	18.38
2	3.2659	Space 1		6.43
3 a	6.2738	4.20811	ACRYLIC	4.56
4 a	-5.3778	Space 2		4.44
5 a	3.6080	1.44262	ACRYLIC	4.82
6 a	5.4227	1.16042		5.08
7 a	-5.4227	1.44262	ACRYLIC	5.14
8 a	-3.6080			5.05

## EVEN POLYNOMIAL ASPHERE

SN.	AD	AE	AF	AG	AH	AI
1	1.0654E-04	-1.6347E-06	4.8346E-08	-4.1311E-10	-6.4586E-13	2.5285E-14
3	-1.6510E-03	2.2595E-04	-8.7853E-05	3.8498E-06	9.6269E-07	-7.2923E-08
4	-1.1892E-03	-1.9645E-04	1.1723E-04	-9.3873E-06	-2.5734E-06	2.9434E-07
5	-3.8633E-03	-4.5747E-04	2.0174E-05	-3.2030E-06	-1.0994E-06	-9.8583E-08
6	-1.4714E-03	-1.6908E-04	-7.8496E-05	-6.8306E-06	-2.5379E-07	1.0984E-07
7	1.4714E-03	1.6908E-04	7.8496E-05	6.8306E-06	2.5379E-07	-1.0984E-07
8	3.8633E-03	4.5747E-04	-2.0174E-05	3.2030E-06	1.0994E-06	9.8583E-08

## ZOOM THICKNESSES

EFL	Space 1	Space 2
4.0	6.974	2.041
8.0	2.269	6.746

## SYSTEM FIRST ORDER PROPERTIES, POS 1

FIELD: 38.0° f/ 1.80  
 STOP: 1.73 after surface 4. DIA: 2.8883  
 EFL: 4.00007 FVD: 26.3094 ENP: 12.6909  
 BFL: 1.76484 BRL: 24.5446 EXP: -4.73970

## SYSTEM FIRST ORDER PROPERTIES, POS 2

FIELD: 18.0° f/ 2.50  
 STOP: 1.75 after surface 4. DIA: 3.3551  
 EFL: 7.99927 FVD: 26.3093 ENP: 11.7544  
 BFL: 1.76473 BRL: 24.5446 EXP: -22.6580

TABLE 10

MATERIAL	$N_e$	$V_e$
ACRYLIC	1.4935	57.3
FK5	1.4891	70.2
SK5	1.5914	61.0
FC5	1.4891	70.2
FCD1	1.4984	81.2
POLYCARB	1.5901	29.6
STYRENE	1.5949	30.7
SF2	1.6522	33.6

TABLE 11

Example	$\Phi_{U1}$	$\Phi_{U1S}$	$\Phi_{U1S} / \Phi_{U1}$	$\Phi_{U2}$	$\Phi_{U2S}$	$\Phi_{U2S} / \Phi_{U2}$	$\Phi_{U3}$
1	-.133	-.211	1.59	.146	.179	1.23	.118
2	-.138	-.197	1.43	.184	.091	0.49	.078
3	-.141	-.185	1.31	.126	.169	1.34	.119
4	-.133	-.211	1.59	.146	.182	1.25	.113
5	-.175	-.235	1.34	.155	.189	1.22	.111
6	-.181	-.165	0.91	.106	.153	1.44	.130
7	-.092	-.213	2.32	.154	--	--	.216
8	-.120	-.233	1.94	.143	.076	0.53	.026
9	-.115	-.180	1.57	.150	.079	0.53	.096

TABLE 12

EXAMPLE	UNIT 1			UNIT 2			UNIT 3		
	$M_w$	$M_t$	$M_t/M_w$	$M_w$	$M_t$	$M_t/M_w$	$M_w$	$M_t$	$M_t/M_w$
1				-1.29	-3.62	2.81	.39	.24	.62
2				-.74	-1.53	2.07	.51	.50	.98
3				-1.88	-20.70	11.01	.28	.048	.17
4				-1.33	-3.86	2.90	.38	.22	.58
5				-1.08	-2.43	2.25	.45	.34	.76
6	-.32	-.39	1.22	-2.12	22.40	-10.57	.22	-.039	-.18
7				-.71	-1.42	2.00	.36	.36	1.00
8				-.70	-1.40	2.00	.33	.33	1.00
9				-.71	-1.42	2.00	.63	.63	1.00

TABLE 13

EXAMPLE	$f_1$	$f_2$	$f_3$	$f_{\min}$	$ f_1 /f_{\min}$	$f_2/f_{\min}$	$ f_3 /f_{\min}$
1	-7.50	6.83	8.47	3.80	1.97	1.80	2.22
2	-7.25	5.43	12.80	2.75	2.64	1.97	4.65
3	-7.11	7.93	8.40	3.80	1.87	2.09	2.20
4	-7.50	6.86	8.85	3.82	1.96	1.80	2.31
5	-5.70	6.43	9.00	2.76	2.07	2.33	3.26
6	-5.52	9.45	7.69	4.00	1.38	2.36	1.92
7	-10.90	6.51	4.63	2.75	3.96	2.37	1.68
8	-8.33	7.01	38.46	4.00	2.08	1.75	9.63
9	-8.66	6.66	10.40	4.00	2.17	1.67	2.60

TABLE 14

EXAMPLE	$T_1/f_{\min}$	$T_2/f_{\min}$	$T_3/f_{\min}$	$T_4/f_{\min}$	$T_5/f_{\min}$
1	.77	.81	.66		
2	1.60	1.49	1.39		
3	.66	.85	.30	.38	
4	.77	.81	.66		
5	.33	.99	.36		
6	.75	.64	.82	.29	.38
7	1.38	.83	.52	1.37	
8	1.04	1.37	.66	.36	
9	1.82	1.05	.36	.36	

What is claimed is:

1. A variable power lens system for forming an image of an object, said system having a minimum focal length  $f_{\min}$  and comprising:

(a) a first lens unit having a negative power and a focal length  $f_1$ ;

(b) a second lens unit which (i) is on the image side of said first lens unit, (ii) has a positive power, and (iii) has a focal length  $f_2$ ; and

(c) a third lens unit which is on the image side of said second lens unit, said third lens unit having a focal length  $f_3$ ;

wherein:

the focal length of the lens system is changed by changing the spacing between the first lens unit and the second lens unit; and

the ratio of the absolute value of  $f_1$  to  $f_{\min}$  or the ratio of  $f_2$  to  $f_{\min}$  is greater than about 1.3.

2. The variable power lens system of Claim 1 wherein the ratio of the absolute value of  $f_3$  to  $f_{\min}$  is greater than about 1.3.

3. The variable power lens system of Claim 1 wherein the ratio of the absolute value of  $f_1$  to  $f_{\min}$  and the ratio of  $f_2$  to  $f_{\min}$  are each greater than about 1.3.

4. The variable power lens system of Claim 3 wherein the ratio of the absolute value of  $f_3$  to  $f_{\min}$  is greater than about 1.3.

5. A variable power lens system for forming an image of an object, said system having a minimum focal length  $f_{\min}$  and comprising:

(a) a first lens unit having a negative power and a focal length  $f_1$ ;

(b) a second lens unit which (i) is on the image side of said first lens unit, (ii) has a positive power, and (iii) has a focal length  $f_2$ ; and

(c) a third lens unit which is on the image side of said second lens unit, said third lens unit having a focal length  $f_3$ ;

wherein:

the focal length of the lens system is changed by changing the spacing between the first lens unit and the second lens unit; and

the lens system includes at least one lens element for which the ratio of the thickness of the element to  $f_{\min}$  is greater than about 0.5.

6. The variable power lens system of Claim 5 wherein the lens system includes at least two lens elements for which the ratio of the thickness of the element to  $f_{\min}$  is greater than about 0.5.

7. The variable power lens system of Claim 6 wherein the lens system includes at least three lens elements for which the ratio of the thickness of the element to  $f_{\min}$  is greater than about 0.5.

8. The variable power lens system of Claim 5 wherein the ratio of the absolute value of  $f_1$  to  $f_{\min}$  or the ratio of  $f_2$  to  $f_{\min}$  is greater than about 1.3.

9. The variable power lens system of Claims 1 or 5 wherein the first lens unit includes only negative lens elements, has a negative power  $\Phi_{U1}$  equal to  $1/f_1$ , and includes a lens surface that:

(i) is concave to the image, and

(ii) has a negative power  $\Phi_{U1S}$ , the ratio of  $\Phi_{U1S}$  to  $\Phi_{U1}$  being greater than 1.0.

10. The variable power lens system of Claims 1 or 5 wherein:

the second lens unit has a positive optical power  $\Phi_{U2}$  equal to  $1/f_2$ , and includes a lens surface that:

(i) is concave to the image, and

(ii) has a positive optical power  $\Phi_{U2S}$ , the ratio of  $\Phi_{U2S}$  to  $\Phi_{U2}$  being greater than 1.0; and

the third lens unit has a positive optical power.

11. The variable power lens system of Claims 1 or 5 wherein the third lens unit has at least two surfaces that have optical power, the surface closest to the image having an overall shape which is concave to the image.

12. The variable power lens system of Claim 11 wherein the second lens unit includes at least two surfaces that have optical power, the surface closest to the image having an overall shape which is concave to the image.

13. The variable power lens system of Claims 1 or 5 wherein:

the second lens unit includes at least two surfaces that have optical power, the surface closest to the image having an overall shape which is concave to the image; and

the third lens unit has a positive power.

14. The variable power lens system of Claims 1 or 5 wherein the system has a maximum effective focal length  $f_{\max}$  and wherein:

the first lens unit includes only negative lens elements;

the second lens unit is moveable to change the magnification of the lens system and includes only positive lens elements;

at least one of the first and third lens units is moveable; and

the movement of the second lens unit provides the majority of the change in focal length of the lens system between its maximum and minimum effective focal lengths.

15. A variable power lens system for forming an image of an object, said system comprising:

(a) a first lens unit having a negative power and including only negative lens elements;

(b) a second lens unit which is on the image side of said first lens unit and has a positive power, said second lens unit being moveable to change the

magnification of the lens system and including only positive lens elements; and

(c) a third lens unit which is on the image side of said second lens unit, said third lens unit including means for correcting the lens system's chromatic aberration.

16. The variable power lens system of Claim 15 wherein the means for correcting the lens system's chromatic aberration comprises a diffractive optics surface.

17. The variable power lens system of Claim 15 wherein the means for correcting the lens system's chromatic aberration comprises a color-correcting doublet.

18. The variable power lens system of Claim 17 wherein the each of the lens elements of the doublet include an approximately paraboloidal surface.

19. The variable power lens system of Claims 1, 5, or 15 further comprising a fourth lens unit on the object side of the first lens unit, said fourth lens unit having a positive power.

20. A variable power lens system for forming an image of an object, said system consisting of, from the object side: a positive lens element; a negative lens element that moves for zooming; a positive lens element that moves for compensating; and a positive lens unit.

21. The variable power lens system of Claim 20 wherein the positive lens unit comprises a color correcting doublet.

22. The variable power lens system of Claims 1, 5, 15, or 20 wherein the system includes at least one aspheric surface.

23. The variable power lens system of Claims 1, 5, 15, or 20 wherein the system is a zoom lens system.

24. An optical system comprising the lens system of Claims 1, 5, 15, or 20 and an electronic imaging system for detecting the image produced by the lens system.

25. The optical system of Claim 24 wherein the electronic imaging system comprises a charged coupled device.

26. An optical system comprising a variable power lens system for forming an image of an object and an electronic imaging system for detecting said image, said lens system comprising three lens units at least one of which consists of a single lens element whose thickness is at least about 0.5 times the diagonal of the image.

27. The optical system of Claim 26 wherein the electronic imaging system comprises a charged couple device.

28. An optical system comprising a variable power lens system for forming an image of an object and an electronic imaging system for detecting said image, said electronic imaging system comprising an electronic component having a light sensitive surface and said lens system comprising three lens units at least one of which consists of a single lens element whose thickness is at least about 0.5 times the maximum transverse dimension of said light sensitive surface.

29. The optical system of Claim 28 wherein the electronic component is a charged couple device (CCD) and said maximum transverse dimension is the diagonal of the CCD's light sensitive surface.

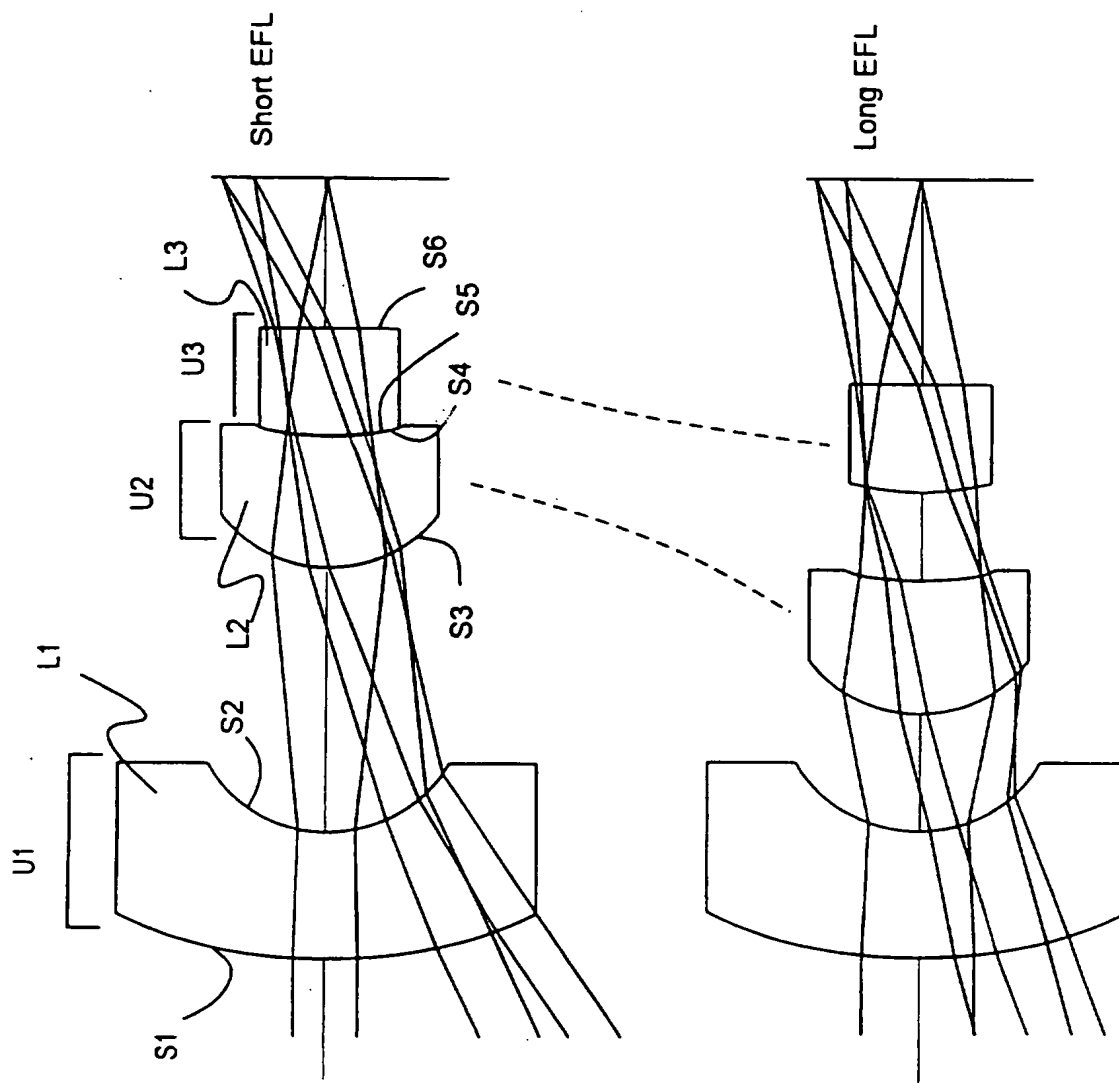


Figure 1

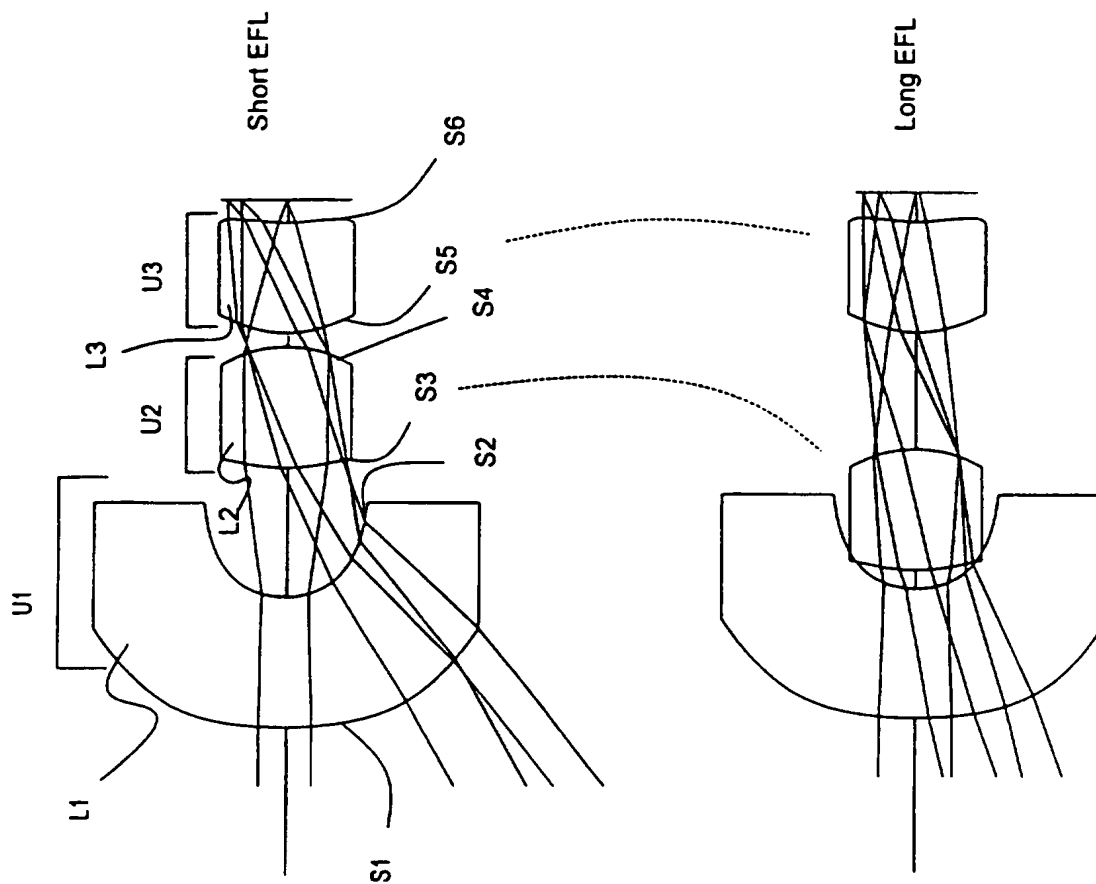


Figure 2

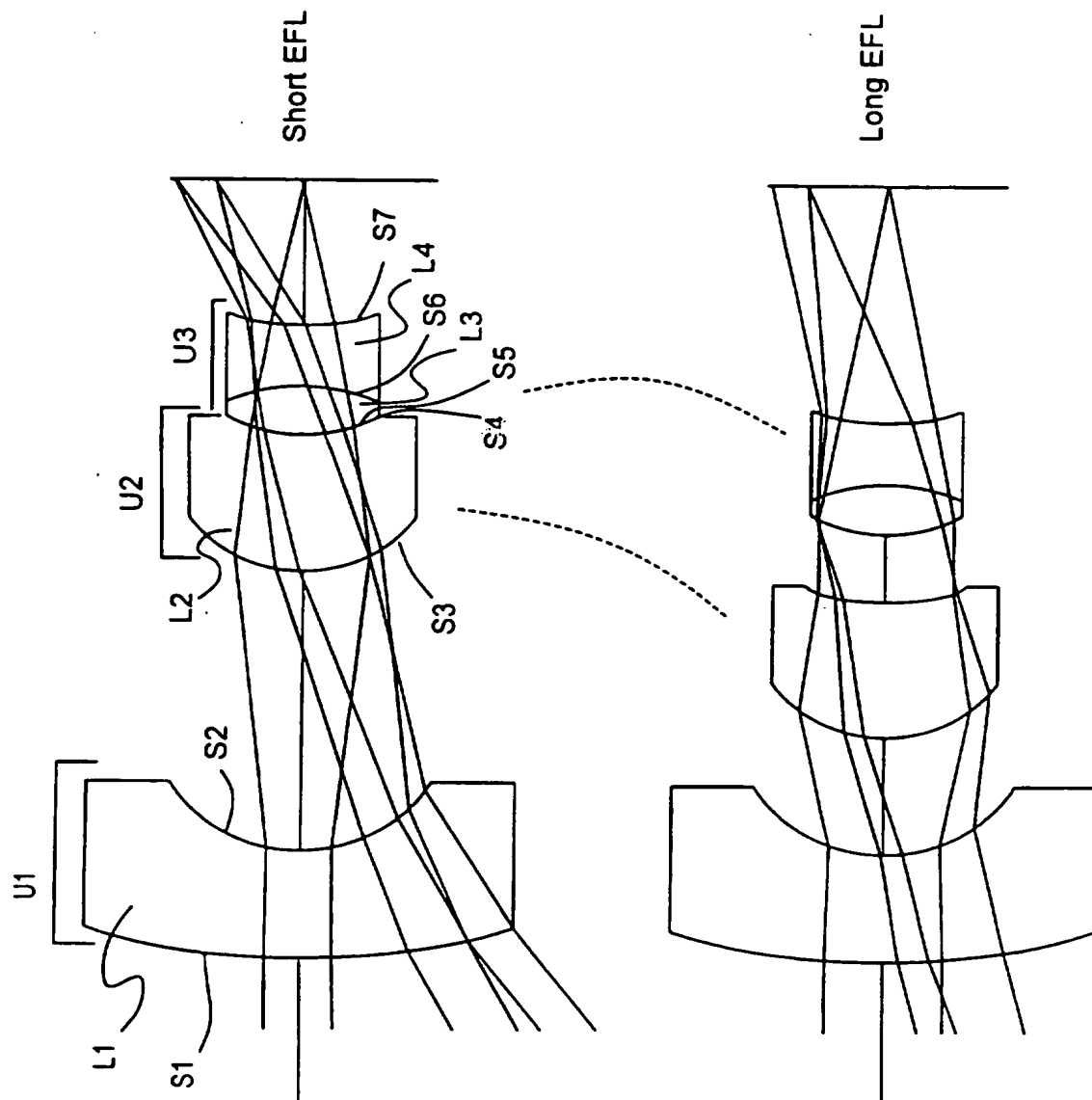


Figure 3

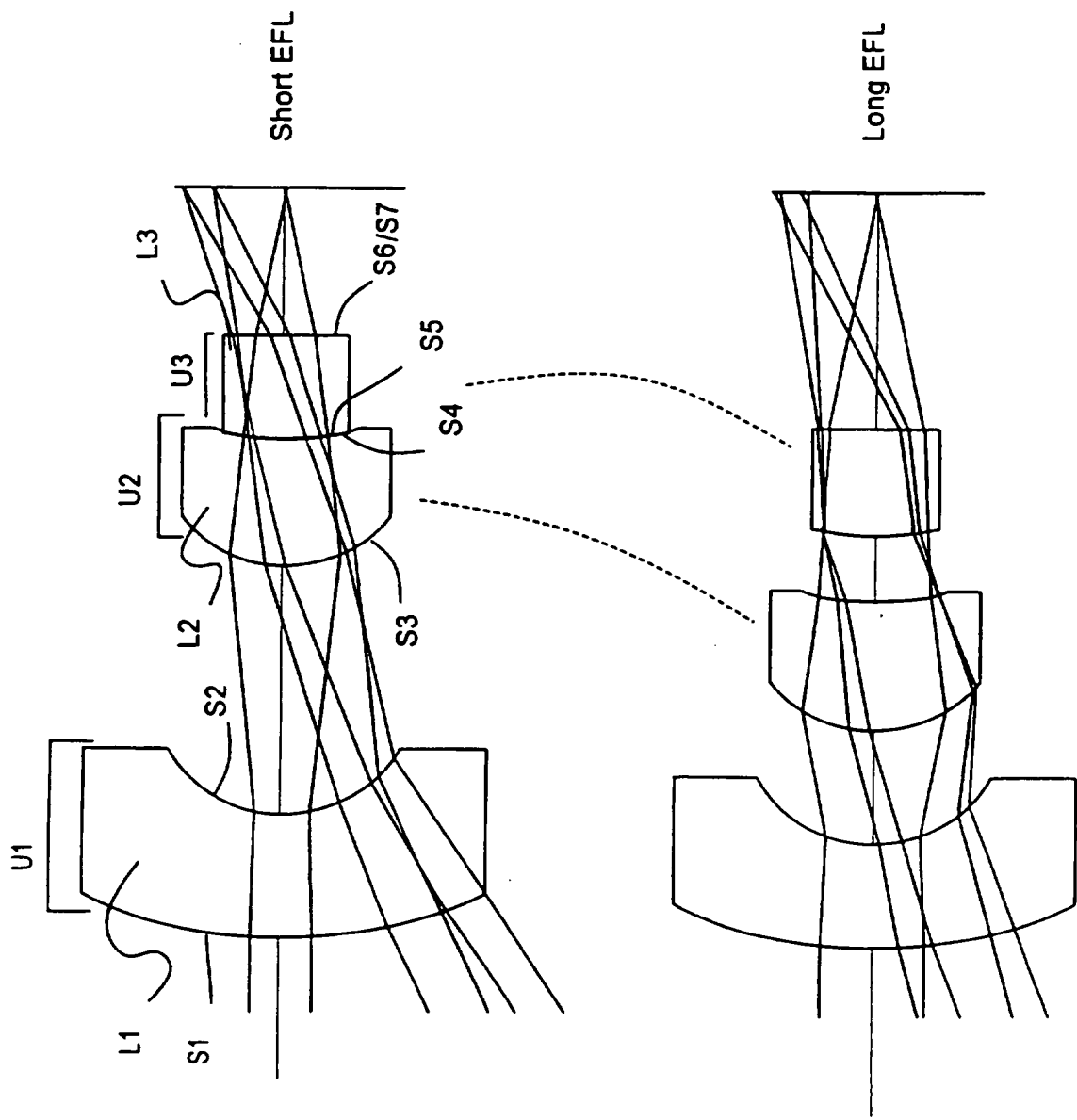


Figure 4

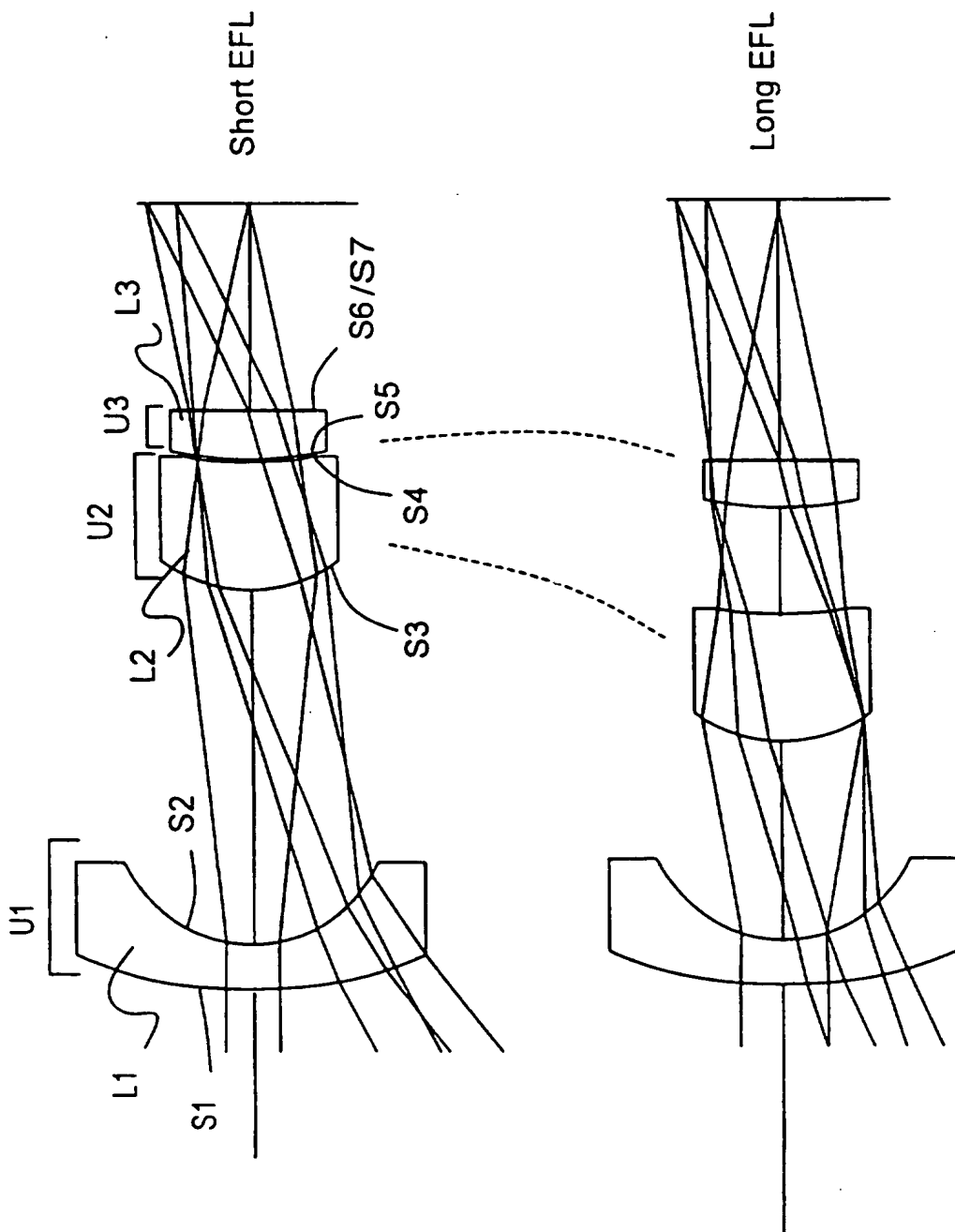


Figure 5

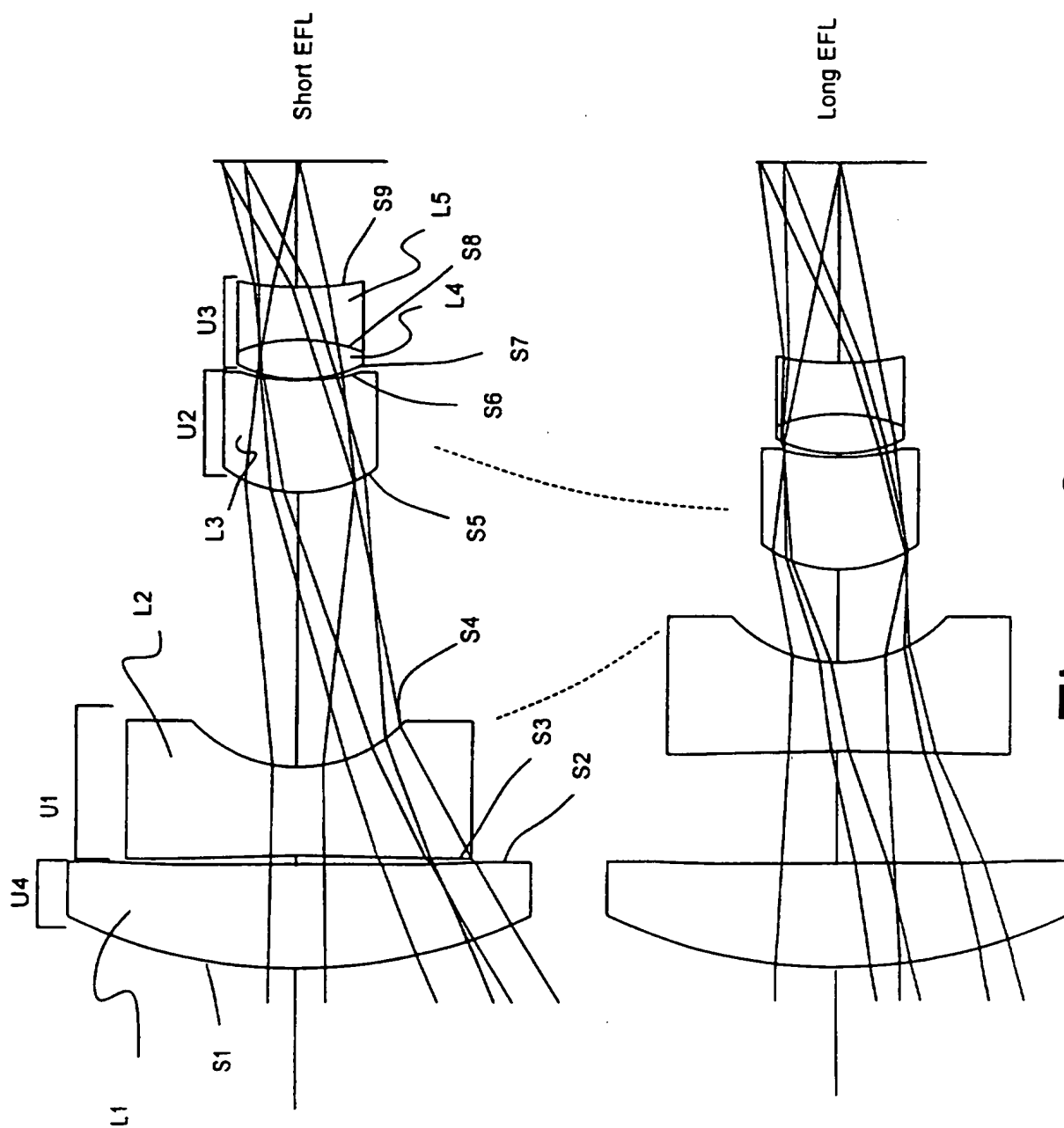
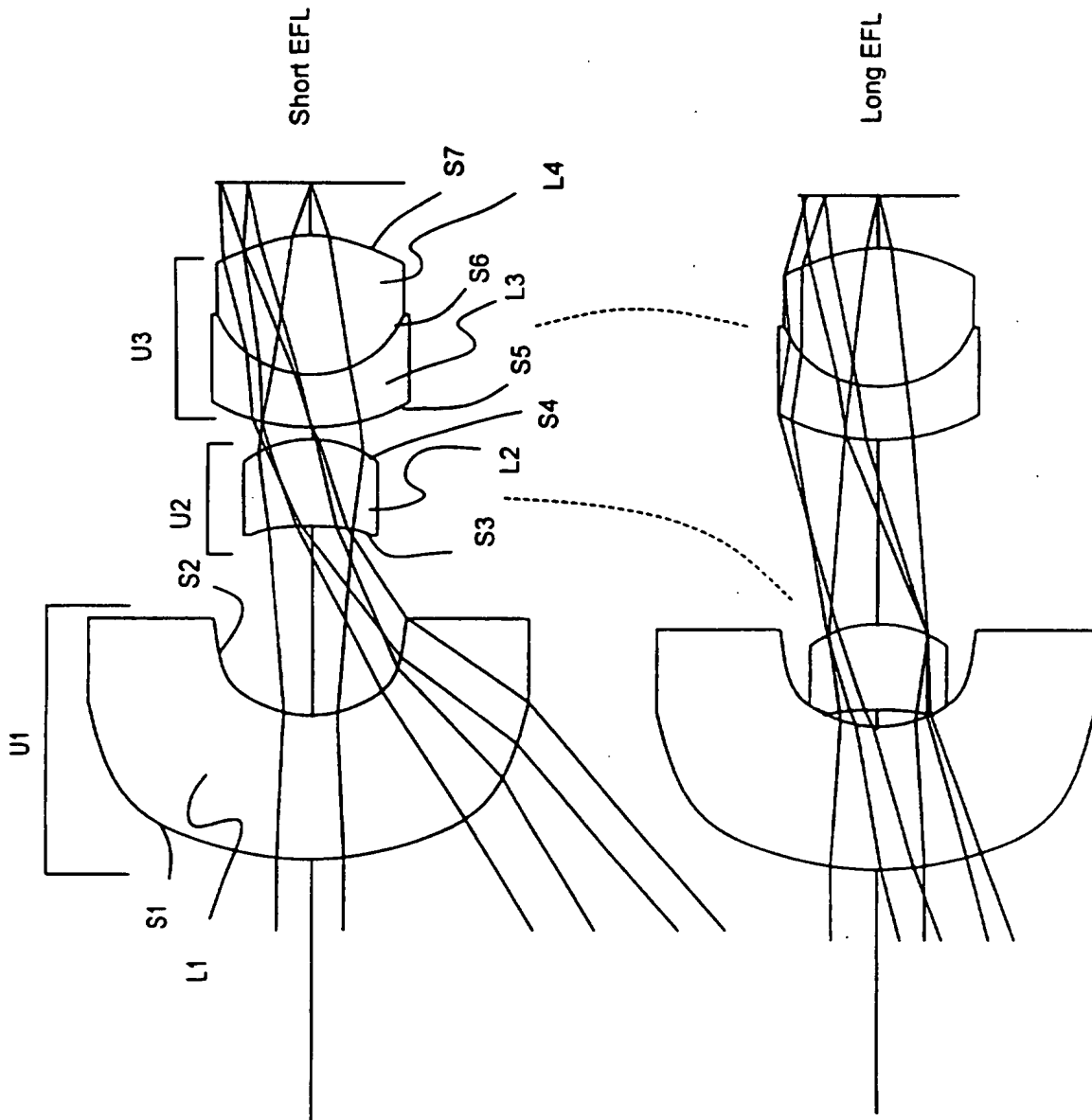


Figure 6

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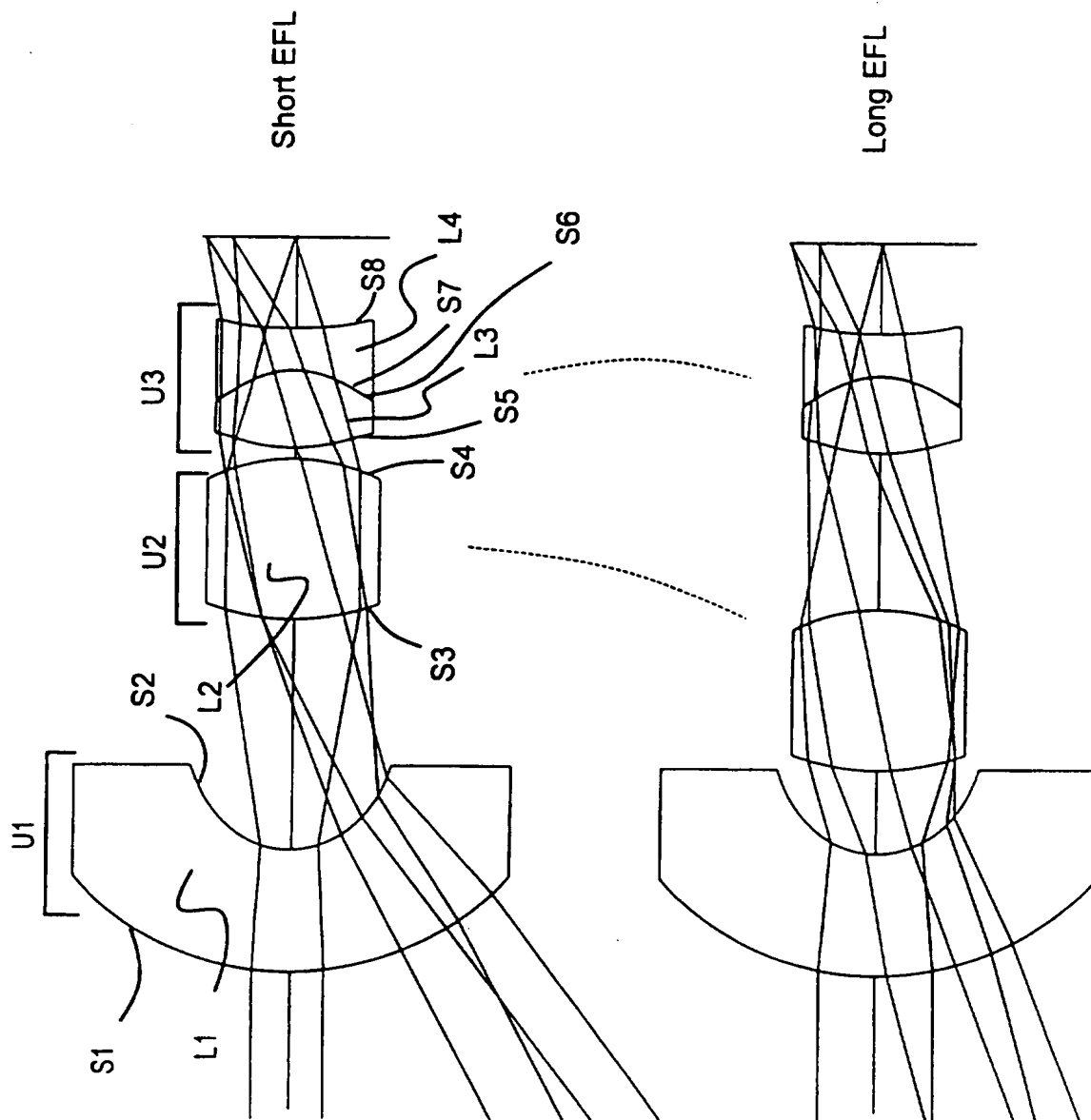


Figure 8

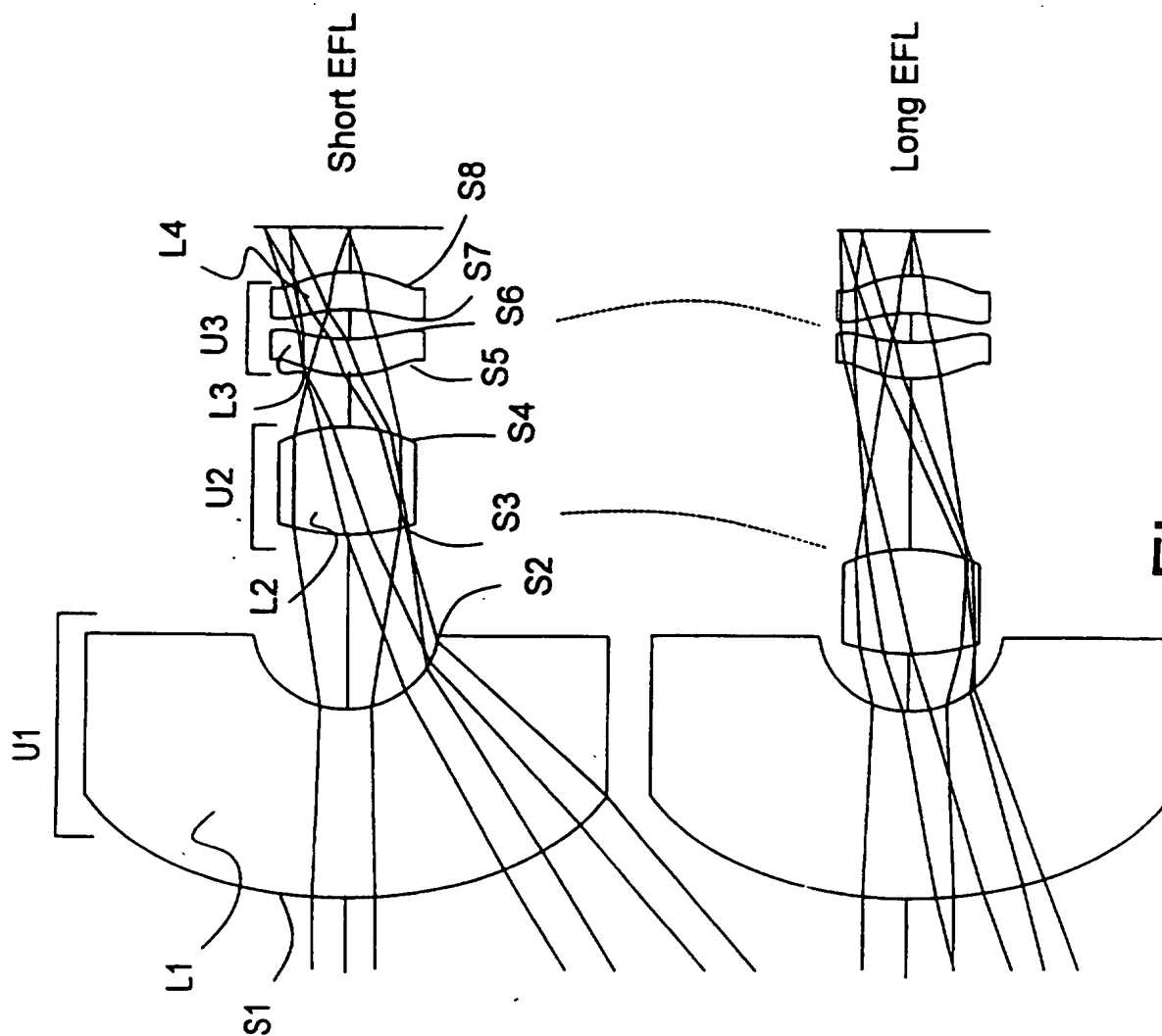


Figure 9

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US95/16522

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G02C 15/14

US CL :359/689, 687, 708

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/689, 687, 708

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A, T	US, A, 5,485,313 (BETENSKY) 01 January 1996	1-20
A	US, A, 5,357,374 (OHNO) 18 October 1994	1-20
A	US, A, 5,268,792 (KREITZER ET AL) 07 December 1993	1-20
A	US, A, 5,268,790 (CHEN) 07 December 1993	21-29



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:		*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A*	document defining the general state of the art which is not considered to be of particular relevance	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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*O*	document referring to an oral disclosure, use, exhibition or other means		
*P*	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

23 APRIL 1996

Date of mailing of the international search report

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